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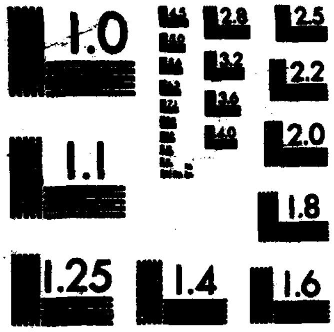

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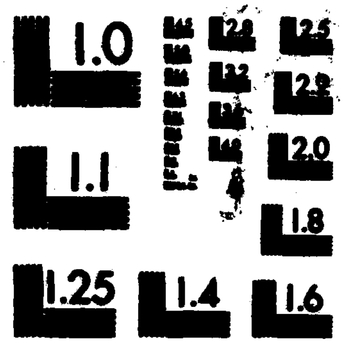

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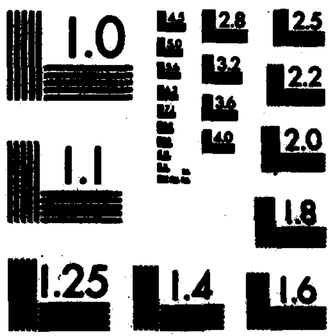

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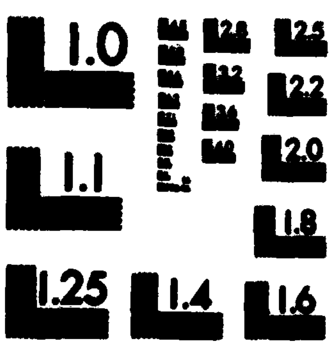

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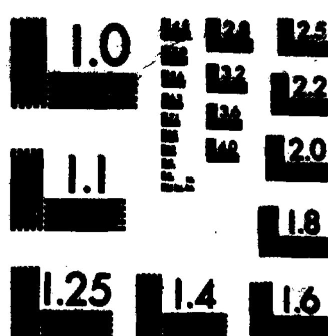

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UCLA School of Engineering and Applied Science

"FINAL REPORT" - CONTRACT NO. DAAG-29-79-C-0050 ARO 15965.14-EL

By:
N. G. Alexopoulos and
R. S. Elliott

Sponsored by:
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This is the final report for U.S. Army Research Office Contract No. 29-79-C-0050. It contains a summary of the most significant results on Stripline-Fed Slot Arrays (Task 2), Mutual Coupling from Far-Field Measurements (Task 3), and Research on Microstrip Dipoles (Task 4). A List of publications and personnel is provided.

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FINAL REPORT - CONTRACT NO. DAAG 29-79-C-0050

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ABSTRACT

This is the final report for U.S. Army Research Office Contract No. DAAG 29-79-C-0050. It contains a summary of the most significant results on Stripline-Fed Slot Arrays (Task 2), Mutual Coupling from Far-Field Measurements (Task 3), and Research on Microstrip Dipoles (Task 4). A list of publications and personnel is provided.

The following general problems were addressed to the duration of this contract:

a) Stripline-Fed Slot Arrays (Task 2)

b) Mutual Coupling from Far-Field Data (Task 3)

c) Research on Microstrip Dipoles (Task 4)

A summary of the obtained results is provided herewith.

TASK 2

Stripline-fed slot arrays are potentially attractive for use in both microwave and millimeter wave applications. Unlike microstrip dipole arrays, they do not suffer from the disadvantage of an exposed (and thus interacting) feed structure; and unlike waveguide-fed slot arrays, they do not suffer from the requirement for a feeding structure which must have a rectangular disposition. The possibility exists that a single radiating slot can be contained in a cell which is shaped like a partially-eaten piece of pie, with the four vertical walls composed of pin curtains. The strip enters and leaves this region, at arbitrary points, through gaps in the curtains. This arrangement permits the radiating slots in a seeker antenna to be disposed along concentric circles, an arrangement which has been shown to produce superior sum patterns.

This approach is being investigated in a sequence of Ph.D. dissertations at UCLA. Earlier (1978), P.K. Park developed a theory for longitudinal slots centered on the broadwall of a boxed stripline, with the strip snaking under the slots, the excitation of each slot being governed by the angle at which the strip crossed under it. He accounted for mutual coupling and designed an eight element linear array to test the theory. Experiment and theory were in excellent agreement.

Park's array gave transverse polarization and could not be scanned to the vicinity of endfire because of the element pattern. An obvious next step was to study transverse slots fed by boxed stripline, an arrangement which produces longitudinal polarization and a semi-circular element pattern, thus permitting endfire arrays.

This new geometry was studied by R. Shavit for his Ph.D. dissertation, with partial support coming from the present Army Research grant. Shavit centered the transverse slot in the upper broadwall of the boxed stripline and let the strip pass under it without snaking. In order to reduce the excitation to a practical level, he had to displace the longitudinal strip so that it passed under the slot near an extremity. He used two pin curtains, symmetrically disposed in transverse planes on each side of the slot, in order to contain the TE_{10} mode, since the $\underline{a}$ dimension of the box had to exceed $\lambda/2$ in order to accommodate the slot. Gaps in the pin curtains permitted entry and exit of the strip.

A prototype device showed experimentally that this cell, consisting of boxed stripline, pin curtains, and slot, was practical for use as an array element. The normalized slot impedance Z/Z_o was governed by the slot length and by the offset of the strip relative to the slot end.

The next step was to develop a theory which would explain the behavior of Z/Z_o versus length and offset. Shavit did this by assuming that $\underline{E}$ in the slot aperture was longitudinal and a function only of the transverse coordinate. He constructed an integral equation in the unknown $\underline{E}$ by matching tangential $\underline{H}$ in the slot, using a half-space external Green's function, and an internal Green's function represented by a two-dimensional sum of modes. A method-of-moments solution was obtained using point matching and pulse functions. $\underline{E}$ in the slot was found to be essentially a bowed-out equiphase cosinusoid. Near-field measurements confirmed this.

When this $\underline{E}$ distribution in the slot was used to determine Z/Z_o versus length and offset theoretically, agreement with experiment was satisfactory, but not sufficiently precise. The reason was traced to the sensitivity required in knowing $\underline{E}$ in the slot in the region near the strip. This is due to the extremely rapid fall-off of the strip's fringing field. Shavit discovered that a modest perturbation of the $\underline{E}$ field he had deduced using the method-of-moments was sufficient to bring theory and experiment for Z/Z_o into complete agreement.

With this accomplishment, Shavit developed a design procedure for a slot array which would take external mutual coupling into account. His procedure applies equally well for planar and linear arrays, but for economy reasons a test was made for a six-element linear array. An input match was prescribed, togethar with a 20dB Dolph-Chebyshev pattern. Agreement between theory and experiment was excellent. The pattern was well-formed with side lobes interspersed by deep nulls. The side lobe level did not exceed -18dB in a 2.5% bandwidth centered about the design frequency. In that bandwidth, the input VSWR reached a minimum of 1.07. We feel that Shavit has fully demonstrated the properties of this array element.

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PERSONNEL

R. Shavit, Graduate Student (received Ph.D. in June, 1982)
R. S. Elliott, Faculty

TASK 3

As is well known, many "terminal" antenna properties may be directly deduced from a knowledge of the total antenna transmitting pattern; i.e., over "visible" and "invisible" values. The thrust of our activity contends with the question of reconstruction of the total pattern from a segment of the "visible" or measured radiative pattern. From this extrapolation, our hope is to calculate such properties as mutual impedance, self-impedance and eventually determine possible environmental factors, manifested through change in measured patterns, influencing these terminal quantities. Lastly, certain problems in pattern synthesis hint at natural solution in the process of these investigations; we shall now treat each in turn.

The point of departure was the pattern function itself. The extrapolation thereof from measured data is a very delicate issue--the general class of finite radiators was seen to have analytic patterns with no further constraint. The classical solution to this extrapolation; i.e., Miller's extrapolation or singular integral equation solution, ala Lavretier, was found both unwieldly and inaccurate. Where upon it was decided to restrict the class of radiators to those with bandlimited patterns; e.g., planar aperture or line source antennae. Thus changed, the problem was still ill-posed but well considered. The traditional solution of spheroidal harmonies was seen intractable. An attempt to extend the methods of J. L. Harris--a sampling series-point match technique was of no great success; however, dividends for the subsequently developed "impedance series" were noted. An exhaustive literature search then produced the Gerchberg/Papoulis iterative error energy reduction technique. This, solved in one-step fashion by Cadzow, provided a facile, reliable solution to the extrapolation of bandlimited functions. Various formulations were successfully coded and an extension to multi-dimensional (2^d) form provided. Extensive numerical experiment noted that 2-3 to 1 ratios of extrapolation on measured data were not out of the question.

Whereupon the problem of impedance from "total" pattern was considered. In a plane wave spectral setting, expressions were developed that gave self and mutual couplings from both "visible" and "near-visible" data. These expressions, involving integral/sampling series transformations, were found fast convergent $\left(\text{e.g. } O(1/n^4)\right)$ and when used in conjunction with the aforementioned extrapolation techniques were quite capable of estimating impedance parameters within $\sim$ 10-15% accuracy for measured data. The case of mutual coupling between two slots, self impedance of a simple TEM slot radiator, and the mutual coupling of two linear 1/2-wave dipole radiators were considered in detail. These results were presented at the recent (May'81) IEEE/APS Antenna Conference New Mexico. Some of the theoretical implications of these studies were provided earlier exposure in another paper given in Los Angeles at the 1981 Conference. Lastly, the pattern-coupling theory of Washylkiwskyj and Kahn for the idealized Canonical Minimum Scattering Antennae has been much utilized in the present context.

Work inchoate includes the coupling study and impedance (self) of rectangular aperture antennae and general 2^d extrapolations of measured, i.e., noisy data. Also, note the problem of bandlimited pattern synthesis is aided somewhat by the availability of an extrapolatory algorithm as it is then possible to infer reactive consequences ("invisible") of "visible" pattern design requirements. A variational pattern synthesis ala Rhodes that allows quasi-optimal control over both radiative and reactive properties has been developed and awaits exploration. Also, coincidental with much of the above is the problem of phase measurement and/or recovery from intensity data. An effort is underway to assess the practicability of such extension/measurements for if it were possible to measure phase with accuracy (prior examples require power/intensity data to generate the extrapolation), it would then be possible to broaden considerably the applicable class of radiators to which the theory applies.

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REPORTS

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PERSONNEL

N. G. Alexopoulos
G. Franceschetti
S. Chaiken

TASK 4

In Task 4, the problem of printed circuit antennas has been investigated. The aim in this task has been to approach the problem in a fundamental way so that the full effect of substrate properties is taken into account precisely. A model of printed circuit antennas which accounts for arbitrary substrate thickness and permittivity has been derived. The model is based on obtaining the exact Green's function for the boundary value problem, thus accounting for all wave phenomena such as surface waves, evanescent and radiation modes. This Green's function is then incorporated into a Pocklington-type integral equation which must be solved numerically; e.g., by the use of the method of moments for the determination of the antenna current distribution. Once this solution has been achieved, the basic antenna characteristics such as input and mutual impedance, radiation pattern, etc., are obtained.

In the derivation of this model, a very important and basic problem has been solved successfully, namely, the resulting Sommerfeld-type integrals in the Green's function. These integrals involve semi-infinite integration along the real axis with singularities due to surface wave poles. They are excessively difficult to integrate out numerically when source and field points are on the substrate, as it occurs in the attempt to obtain the printed antenna current distribution. Analytical techniques have been developed which in combination with the method of moments have provided the desired solutions to the Pocklington integral equation for the current distribution.

The initial printed antennas considered were limited to dipoles due to excessive computer cost. This cost of about $80.00 per input impedance versus frequency curve is being reduced currently by an order of magnitude down to $4.00 per input impedance curve. This will be a major accomplishment in that more complicated geometries including the feeding structure will be amenable to computation. In fact, the solution to coupled integral equations of the Pocklington type will be feasible so that the current distribution can be evaluated as a two dimensional vector quantity in two variables.

At the moment with the algorithm which we have developed, the following computations have been performed:

a. Current distribution of printed dipoles

b. Input and Mutual Impedance between various configurations of printed dipoles

c. Radiation Patterns

d. Radiation Efficiencies

e. Bandwidth

These computations have proven the strong effect of the TM and TE substrate surface wave modes on the antenna properties. Some basic conclusions in understanding the radiation mechanism of microstrip antennas have been arrived at, with far reaching significance in the future design of such antennas, especially in the millimeter wave region where substrate thickness is an important factor. Some of these conclusions are:

a. Radiation efficiency is maximum for any given substrate material provided the substrate thickness is chosen at the cut-off of the first TE surface wave mode.

b. Bandwidth is maximum at a thickness slightly beyond the TE cut-off point. This bandwidth increases monotonically with substrate permittivity.

c. The bandwidth obtained at the optimum radiation efficiency substrate thickness increases with substrate relative permittivity until $\varepsilon_r \simeq 9.5$ and thereafter it decreases monotonically.

d. The radiation pattern consists of three basic current mode distributions for resonant dipoles. These current distributions are determined by the substrate thickness for a given relative permittivity and they yield three different radiation patterns which consist of a single, double or triple lobe structure, both in the $\overline{E}$ and $\overline{H}$ plane cuts.

e. For specific substrate thickness and relative permittivity values, radiation along the axis of the dipole on the substrate is possible due to lateral waves..

f. Radiation efficiency is less than 50% when the substrate permittivity is chosen to be $\epsilon_r \gtrsim 4.5$.

The hierarchy of understanding of the basic radiation properties of printed antennas having been established, the research is now proceeding with the computation of feeding effects and strip antenna geometries with emphasis on millimeter wave applications.

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7) Rana, I.E., Alexopoulos, N.G., Katehi, P.B. "Theory of Microstrip Yagi-Uda Arrays," Radio Science, 16-6: 1077-1079, November-December, 1981.

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2) Katehi, P.B., Alexopoulos, N.G "On the Effect of Substrate Thickness and Permittivity on Printed Circuit Antennas," IEEE Trans. on Antennas and Propagation.

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D. SUBMITTED FOR PUBLICATION

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PERSONNEL

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